Renewable and Sustainable Energy Reviews 39 (2014) 35–41

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Municipal solid waste (MSW) as a source of renewable energy in Bangladesh: Revisited

H.M. Zakir Hossain [a,*], Quazi Hasna Hossain [b], Md. Minhaj Uddin Monir [a], Md. Tofayal Ahmed [a]

[a] Department of Petroleum and Mining Engineering, Jessore University of Science and Technology, Jessore 7408, Bangladesh
[b] Department of Geoscience, Shimane University, 1060 Nishikawatsu, Matsue 690-8504, Japan

ARTICLE INFO

Article history:
Received 24 June 2012
Received in revised form
24 May 2014
Accepted 6 July 2014
Available online 26 July 2014

Keywords:
Renewable energy
Municipal solid waste
Mega-cities
Bangladesh

ABSTRACT

With radically increased population, rapid economic growth and expansion of urbanization and industrialization, mega-cities of Bangladesh are faces the complexity of municipal solid waste (MSW) management. The purpose of this paper is to review the types of MSW that are currently being used for renewable energy sources. To meet up the power supply for city dwellers and reducing space for new landfills, waste-to-energy (WTE) incineration is playing a vital role for renewable energy production from discarded MSW. Incineration of MSW is complex owing to its low calorific value (~3000 kJ/kg) and high water content (~60%). MSW in Bangladesh contains relatively high proportion of organic matter (74.6%) than paper (9.1%) and plastic (3.5%). Using landfill gas recovery process, generation of electricity from MSW in six mega-cities is ~186,408 kW h/day. Therefore, WTE incineration system contributes greater supply of renewable energy in Bangladesh.

Contents

1. Introduction

The renewable sources of energy are those that can be refilled by nature like hydropower, wind power, solar power, and biomass [1]. The use of this energy for power generation has grown steadily over the past few decades owing to increasing public awareness over air pollution and large scale climate changes [2]. Most of the developed countries such as U.S.A., Europe, China, Singapore, Japan etc. generate electricity from their solid wastes. Recently, municipal solid waste (MSW) is widely used to generate waste-to-energy (WTE) by the conventional technology such as either direct combustion (e.g., incineration/combustion, pyrolysis, and gasification) or production of combustible fuels in the form of methane, hydrogen and other synthetic fuels (e.g., anaerobic digestion and refuse-derived fuel) are also available in the world [1,3]. Using the energy produced from MSW, combined heat and power in the preferred option for maximization overall energy efficiency [3]. Discarded MSW is a viable source of energy for electricity generation and minimization of green house gas emissions [1,2]. The advanced MSW management technology with the benefit of recovering energy from the solid waste is a promising alternative in resolving the waste disposal complexity in the country.

Bangladesh is located in the northeastern part of the Indian subcontinent, which is bounded by the Shillong Plateau to the

* Corresponding author. Tel.: +880 421 62038; fax: +880 421 61199.
E-mail address: zakirgsd@yahoo.com (H.M. Zakir Hossain).

http://dx.doi.org/10.1016/j.rser.2014.07.007
1364-0321/

Fig. 1. Generalized map of Bangladesh showing location of the studied mega-cities.

north and the Bay of Bengal to the south (Fig. 1). The total area of the country is 147,570 km^2. Bangladesh is a densely populated countries of the world, with a population of about 142.32 millions, and its population will be increased ca. 170 millions by 2020 [4–6]. Therefore, large population in the country's with only limited natural resources (natural gas and coal), and cover about 30% energy supply within internal sources, and merely 30% people of the country population has access to electricity [6]. Government of Bangladesh takes initiatives to imports electricity from neighboring countries. Thus, energy plays a vital role in the socio-economic

development and lifestyle improvement in Bangladesh. With increased population and sustained economic growth in the recent eras, Bangladesh is undergoing rapid rate of urbanization and industrialization. The total population increased from 76.4 million in 1974 to 142.32 million in 2011 [4,7], and the country's urbanization rate increased from 8.9% to 28% [8].

MSW refers to the materials discarded in urban areas, including predominantly house hold wastes combined with a minor portion of commercial wastes, collected and disposed by the municipalities. The U.S. Environmental Protection Agency considers MSW to be a renewable energy resource as the waste would otherwise be sent to landfills [9], and it also contains a high proportion of biomass materials [1,3], such as food waste, paper/cardboard, wood, yard trimmings, cotton, leather etc. Fossil fuel materials such as plastics, rubber, fabrics are also present in MSW.

The aim of this paper is to present a comprehensive data set of MSW and to generate renewable energy (electricity) from solid waste in mega-cities of Bangladesh. This also provides an overview of the conditions of MSW disposal and improvement or utilization of WTE incineration industry as well as perspective of MSW as renewable source of energy in the country.

2. Methodology

This study has been conducted in Khulna City Corporation (KCC) area during 2003 to 2005 (Fig. 1). The composition and characteristic of MSW is compared with published data that are derived from five mega-cities (Dhaka, Chittagong, Rajshahi, Barisal and Sylhet) of Bangladesh [10,11]. The data collection and analysis of each ward of the KCC has been considered as an individual unit. A door-to-door detail survey has been conducted with informal and formal questionnaires during field period in the KCC. Approximately 1000 individuals are randomly interviewed following the traditional methods proposed by Pratt and Loizos [12]. Direct observations, separation of solid waste as well as literature review are also added. The solid waste management service in KCC organizes waste collection from approximately 1200 open masonry dustbins or containers of City Corporation located on roadsides throughout the city. Households and shopkeepers are expected to dispose their domestic or trade waste into the masonry dustbins. A considerable amount of waste is found on roads, streets, footpaths, lanes, open drains and drain sides. These wastes are then collected in case baskets or hand carts to dump them at the nearest collection points or masonry dustbins or containers. Finally, the waste collects by municipalities large trucks/vehicles from different roadside bins or containers to transfer dumping into the final disposal sites. The primary, secondary and final disposal sites have been visited to identify and quantify different types of solid wastes. Quantity and percentage of different solid wastes have been calculated from 1 m^3 of solid waste.

3. Composition and significance of generated MSW

This study covers only management of MSW in KCC. Khulna is the third largest city in Bangladesh. The increasing population in the city has created environmental degradation through population due to huge amount of wastes and its unsafe disposal [13]. These wastes are sent to the disposal sites mainly low-lying areas without any scientific approach, thus creating severe adverse impacts on environment and public health through promoting spreading of diseases, causing aesthetic problem, emitting bad odor, producing poisonous gases, polluting water bodies, and contamination of soils [14]. Waste is one of the major problems that need to be dealt with strongly.

In urban areas, KCC is responsible for providing essential services toward waste management such as collection, transportation, disposal and treatment of solid waste. Investigated MSW are mainly non-hazardous waste, generated by households, restaurants, hotels, shops, offices, markets, and industries. Waste from street sweepings is also included. Generation of MSW is increasing day by day in conjunction with fast population growth and ongoing urbanization. The composition of MSW is closely related to the level of economic development and lifestyle of the city residents [15,16]. However, the rural to urban migration of people has contributed more than 40% of the change in urban population [8]. Sources and characteristics of urban solid wastes in Bangladesh are shown in Table 1.

Management of wastes refers to the national control of the overall aspects of its life cycle. Waste management comprises of waste collection, means of disposal and assessment of the components. Better waste management systems would have played a significant role in controlling their adverse environmental impact in the country. At present, there is no rigorous estimate of the waste generation per capita in the major cities of Bangladesh. The estimate of annual generated waste in the city is based on counting the number of collected trucks/vehicles that go to the only existing dumping site. Generally, a large number of wastes remain uncollected in various parts of the city and the collection trucks/vehicles are not always fully loaded. Therefore, the total volume of generated waste is much lower than that of the original amount.

The amount of produce MSW in KCC is about 59 5t per day with an annual growth of waste generation is about 5.3% [17]. The total MSW in six mega-cities is about 7765 t per day (Table 2; Fig. 2), which is very close to the study of Alamgir and Ahsan [10] about 7590 t per day. The composition of MSW in KCC area is 80.0% organic matter, 9.4% paper, 3.0% plastic, 0.4% textile and wood, 0.7% leather and rubber, 1.2% metal, 0.5% glass and 4.8% other waste (Table 3; Fig. 3). The waste generation in the cities has increased over time. Dhaka City Corporation (DCC) generated approximately 5000 t of solid wastes per day in 2002 and the daily generation would increase to over 15,000 t in 2025 [11]. Similarly, KCC generate more than 1500 t per day and it increases 547,500 million tons per annum in 2021 [17]. In 2008, KCC collects only 60% of the total generated waste per day [14]. The amount of generated MSW in KCC (present study) together other five mega-cities of Bangladesh are shown in Table 2 and Fig. 2. The above results of the MSW analysis signifying that the generated waste in the cities are dominantly organic matter that has potential for composting and/or contribute to the production of biogas as well as renewable energy resources.

4. Discussion

MSW is a heterogenous material and composition of its mainly dependent on socio-economic level of the country and climatic

Table 1
Sources and characteristics of urban solid wastes in Bangladesh.
Source: World Bank survey report.

Types of solid waste	Quantity in percentage
Domestic	40–60
Commercial	5–20
Street sweeping	20–30
Combustible	20–30
Non-combustible	30–40
Moisture	45–50

Table 2
MSW generation in six mega-cities of Bangladesh. KCC, Khulna City Corporation; DCC, Dhaka City Corporation; CCC, Chittagong City Corporation; RCC, Rajshahi City Corporation; BCC, Barisal City Corporation; SCC, Sylhet City Corporation, * means average per capita generation of MSW. DCC, CCC, RCC, BCC and SCC data from Alamgir and Ahsan [10], and Uddin and Mojumder [11]. Electricity generation from landfill process using data and equation from Uddin and Mojumder [11].

Waste type	MSW generation × 10^3 kg/day						Sum waste × 10^3 kg/day
	KCC	DCC	CCC	RCC	BCC	SCC	
Organic matter	470	3647	968	121	105	158	5469
Paper	56	571	130	15	9	18	799
Plastic	18	230	37	7	5	8	305
Textile & wood	8	118	28	3	2	5	164
Leather & rubber	4	75	13	2	1	1	96
Metal	7	107	29	2	2	2	149
Glass	3	37	13	2	1	2	58
Other	29	555	97	18	5	21	725
Total	595	5340	1315	170	130	215	7765
Population (million)	1.50	11.00	3.65	0.45	0.40	0.50	17.50
Per capita (kg/day)	0.397	0.485	0.360	0.378	0.325	0.430	0.396*
Electric power generation (kW h/day) from landfill process	14,328	128,160	31,560	4080	3120	5160	186,408

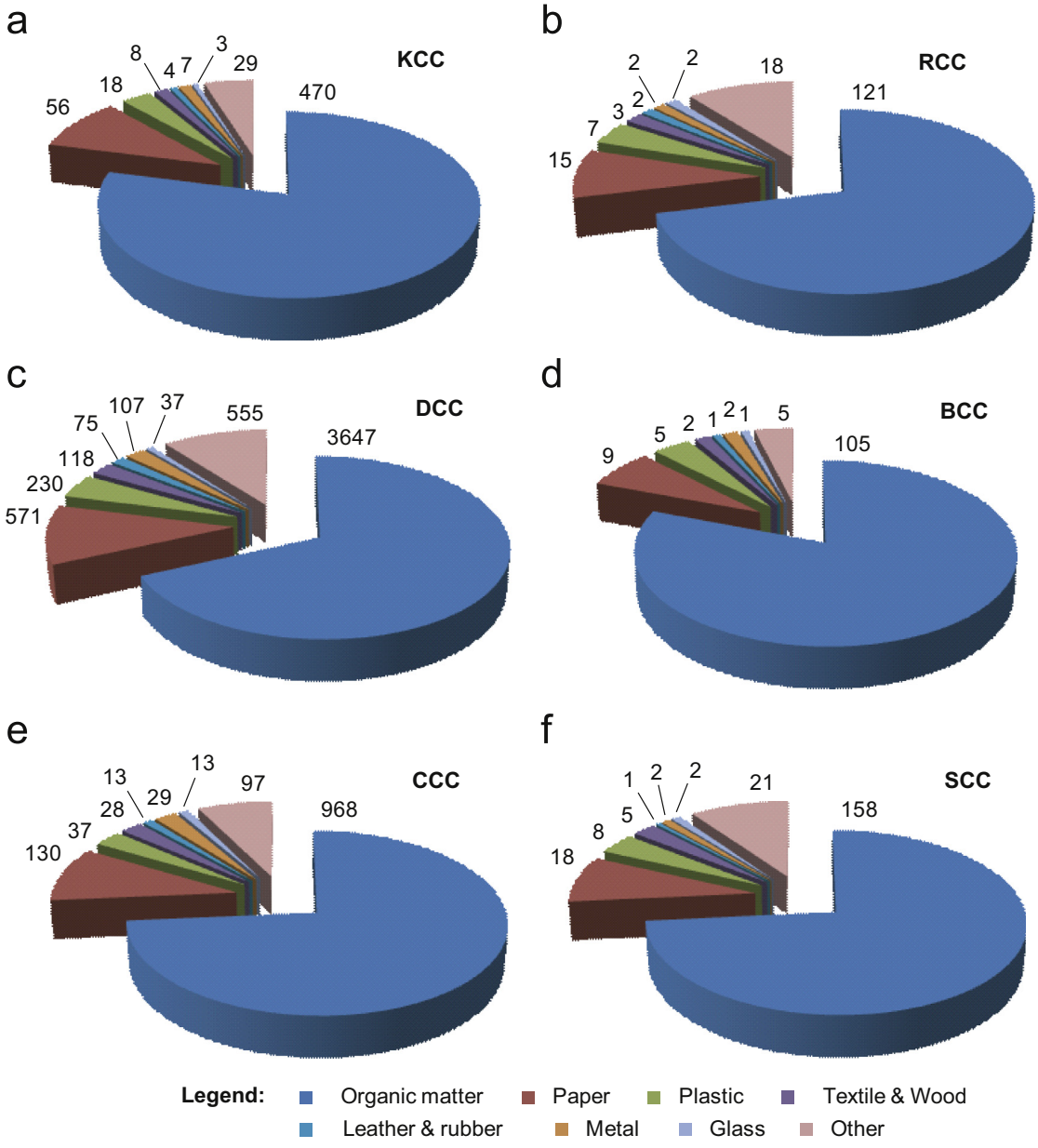

Fig. 2. Composition of generated MSW in six mega-cities of Bangladesh.

conditions. The solid wastes are mainly two types—organic as well as inorganic components. MSW are typically food waste, paper, textile, rubber, plastic, glass, metals and wood are the physical components, where as stones, ceramics and ashes are the miscellaneous inorganic wastes [1]. Generally, food waste constitutes the major fraction of MSW in Bangladesh about 75%, compared to MSW in developed countries like China, U.S.A. and European countries, which constitutes approximately 50% in China and 20% to 30% U.S.A. and European countries [1,18].

Various technologies are now available for generating WTE from MSW worldwide, such as Combustion/Incineration, Anaerobic Digestion/Biomethanation, Pyrolysis/Gasification, Landfill Gas Recovery and Plasma Arc. In the Combustion or Incineration process, wastes are directly burned at high temperatures (800 °C). Heat from combustion can be used as energy source for generate of steam as well as electricity [1]. In the Anaerobic Digestion or Biomethanation process, organic matter of the solid waste is segregate and fed into a closed container. Thus the waste undergoes biodegradation during anaerobic condition with the presence of methanogenic bacteria subsequently generating methane rich biogas. This biogas can be used for generating power or electricity. In the Pyrolysis or Gasification process, organic matter of waste is heated until the organic molecules thermally break down to become a gas comprising smaller molecules collectively known as syngas. The gas produced by pyrolysis is further burned in another combustion engine generator sets or turbines to produce electricity. In the Landfill Gas Recovery process, waste is dumped into a landfill as a result organic matter decomposed subsequently produce of methane gas. It is used as a source of energy or by product for household as well as industrial uses [1]. Landfill gas collection process is of two types—active gas collection procedure and passive gas collection procedure [11]. Plasma Arc process is a very recent technology for disposal of solid waste especially hazardous and radioactive waste.

The country has now been facing an energy crisis due to insufficient power generation capacity compared with basic need and the ageing infrastructure of various existing power generation facilities [19]. However, electricity is a pre-requisite for the modern technological development and rapid economic growth of a nation [20,21]. Almost 70% of the total population in Bangladesh has no access to use electricity [17]. It is important to generate more and more power to meet the basic needs of the growing urban population. Therefore, it is necessary to take initiatives for generation of excess power from discarded MSW. In Bangladesh, the potential sources of renewable energy generation from organic matter. Biogas constitutes mostly of methane, carbon dioxide, hydrogen and hydrogen sulfide [22]. The calorific value of biogas is ~6 kW h/m^3 [11]. The methane generation potential is estimated by the mass fraction (on a dry mass MSW basis) of elemental carbon, hydrogen, oxygen, and nitrogen obtained from the ultimate analysis for biogenic materials (e.g., food waste, vegetables, paper, textiles) [16,23]. The production of methane generation (in m^3 methane/Mg MSW) is much lower than the

Table 3
Average composition (%) of generated MSW in six mega-cities of Bangladesh. Abbreviations as in Table 2. DCC, CCC, RCC, BCC and SCC data from Alamgir and Ahsan [10], and Uddin and Mojumder [11].

Waste type	MSW composition (%)						Average (%)
	KCC	DCC	CCC	RCC	BCC	SCC	
Organic matter	80.0	68.3	73.6	71.1	81.1	73.5	74.6
Paper	9.4	10.7	9.9	8.9	7.2	8.6	9.1
Plastic	3.0	4.3	2.8	4.0	3.5	3.5	3.5
Textile & wood	0.4	2.2	2.1	1.9	1.9	2.1	1.8
Leather & rubber	0.7	1.4	1.0	1.1	0.1	0.6	0.8
Metal	1.2	2.0	2.2	1.1	1.2	1.1	1.5
Glass	0.5	0.7	1.0	1.1	0.5	0.7	0.8
Other	4.8	10.4	7.4	10.8	4.5	9.9	8.0
Total	100	100	100	100	100	100	100

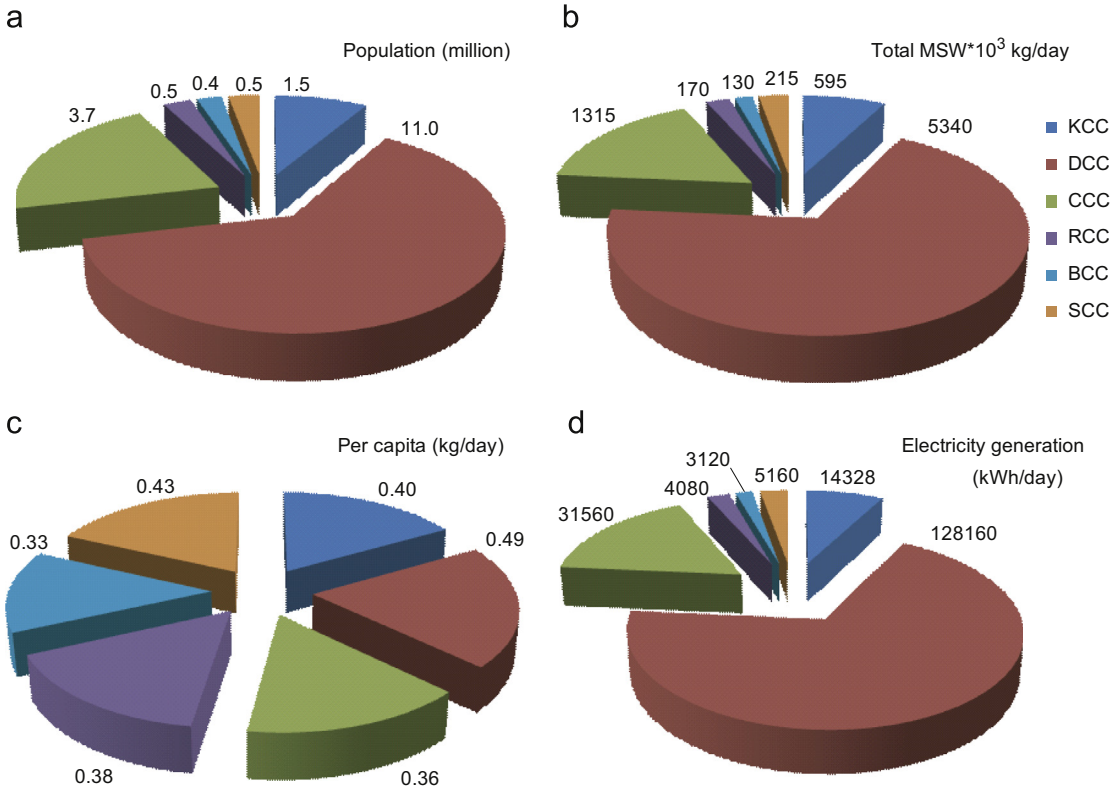

Fig. 3. Population, total MSW, per capita waste generation and electricity generation in six mega-cities of Bangladesh.

standard range of about 50 to 100 kg methane/t MSW (70 to 140 m^3 methane/Mg MSW) for a landfill methane generation estimated by the International Energy Agency (IEA) [24]. Approximately 20% to 30% methane generated from landfill gas recovery process. With the variable renewable energy resources, biomass conversion techniques appear to be one of the best suited for conversion to shaft power/electricity [19]. Uddin and Mojumder [11] reported that active biogas collection procedure in the major landfills of the main cities of Bangladesh can produce ~319,989.36 kW h of electricity per day. The energy conversion efficiency of the process is 25% [11,25]. However, energy content of MSW in six mega-cities is recalculated using the methodology of Uddin and Mojumder [11] that is listed in Table 2. Population, total MSW and per capita waste generation in the six mega-cities of Bangladesh are shown in Fig. 3. The biogas production from landfill in DCC solid waste can produce relatively high electricity ~128,160 kW h/day, while KCC can produce much lower electricity ~14,328 kW h/day (Fig. 3). Electrical power generation using a combined MSW in six mega-cities of Bangladesh provides electricity is about 186,408 kW h/day (Fig. 3). By adopting active gas collection system huge amount of electric energy can be extracted from MSW that could meet the electricity deficit of the country.

Incineration is the primitive WTE technologies that have been developed to convert household, industrial and agriculture waste to energy, and the Mass Burn plants incinerate MSW as received without pre-processing [1,17]. Water content of MSW in Bangladesh is about 60%, and the calorific values range from 2000 to 3000 kJ/kg which are typically less than half of the developed countries. The high moisture content and low calorific value of the MSW substantially increases the incinerator's operating cost [1]. WTE in Bangladesh can be developed as significant integrated waste management strategy while concurrently producing energy, can displace fossil fuels and can diminish pollutant emissions. Electricity generation from MSW is greatly viable in Bangladesh considering the population factor and the subsequent huge amounts of waste generated which are not well managed. Government financial incentives have played a crucial role in simulating the development of WTE incineration and strengthening its position in the renewable energy market. The modified Dulong's formula has been used to calculate total electric power generation from MSW at RCC [6,26]. Carbon, hydrogen, oxygen, nitrogen and sulfur contents of MSW in RCC are 51.50%, 7.92%, 40.57%, 2.35% and 0.13%, respectively [6], which produced total electric power generation approximately 3949.1 kW h/day. Recently, China has developed a grate-circulating fluidized bed combined combustion technology for WTE incineration [18]. This incineration system is compatible for disposal of non-sorted high moisture content and low energy content MSW. China has generated 46.2 million kW h electric powers from 137,325 t MSW incineration in 2006 [18], which are enough to supply electricity over 30,000 city families. Therefore, using the energy produced from solid waste, combined heat and power in the preferred option for maximization overall energy efficiency [3]. Discarded MSW is a viable source of energy for electricity generation and minimization of green house gas emissions [1,2], thus an advanced MSW management technology with the benefit of recovering energy from the solid waste is a promising alternative in solving the MSW disposal problem in the country. Furthermore, expanding WTE incineration industry is expected to make increasingly greater contribution to supplying renewable energy sources in Bangladesh.

5. Conclusion

This paper gives an overview on the potential of MSW in mega-cities of Bangladesh as renewable source of energy. Along with the continued urbanization in mega-cities of Bangladesh, the amount of MSW generation increases significantly. To meet the power supply for city dwellers and reducing space for new landfills, WTE incineration is playing a fundamental role for renewable energy production from discarded MSW. Low calorific value and high water content deficit the power generation from MSW incineration. MSW in Bangladesh contains relatively high proportion of organic matter (74.6%) than paper (9.1%) and plastic (3.5%). Electricity generation from MSW in the six mega-cities is ~186,408 kW h/day using landfill gas recovery process. However, WTE incineration system provides major contribution to supply renewable energy in Bangladesh.

Acknowledgements

The authors are grateful to the authorities of KCC, KDA, PHED, WASA and Prodipan for their cordial help during sample collection and supply of printed materials. We would like to thank Prof. Lawrence L. Kazmerski Editor-in-Chief and two anonymous reviewers for their thoughtful comments on earlier drafts of this manuscript.

References

[1] Cheng H, Hu Y. Municipal solid waste (MSW) as a renewable source of energy: current and future practices in China. Bioresour Technol 2010;101:3816–24.
[2] Kaplan PO, DeCarolis J, Thorneloe S. Is it better to burn or bury waste for clean electricity generation? Environ Sci Technol 2009;43:1711–7.
[3] Ryu C. Potential of municipal solid waste for renewable energy production and reduction of greenhouse gas emissions in South Korea. J Air Waste Manage Assoc 2010;60:176–83.
[4] BBS (Bangladesh Bureau of Statistics). Census reports. BBS: Dhaka; 2001.
[5] Population Council; 2010. Bangladesh fast facts [see at ⟨http://www.popcouncil.org/countries/bangladesh⟩ asp: January 12, 2011].
[6] Rouf MA. Prospect of electric energy from solid wastes of Rajshahi City Corporation: a metropolitan city in Bangladesh. In: Presented at the second international conference on environmental engineering and applications IPCBEE 17 2011.
[7] Population & housing census report. Bangladesh Bureau of Statistics; 2011.
[8] Haider, AK. Challenges for sustainable development: rapid urbanization, poverty and capabilities in Bangladesh; 2008. [See at ⟨http://mpra.ub.uni-muenchen.de/9290/MPRA⟩ paper no. 9290, posted 24, 2008].
[9] U.S. Environmental Protection Agency. Solid waste management and greenhouse gases: a life-cycle assessment of emissions and sinks, 3rd ed. U.S. Environmental Protection Agency; 2006.
[10] Alamgir M, Ahsan A. Municipal solid waste and recovery potential: Bangladesh perspective. Iran J Environ Health Sci Eng 2007;4:67–76.
[11] Uddin MM, Mojumder MSS. Biogas production from municipal waste: prospect in Bangladesh. J Sel Areas Renewable Sustainable Energy 2011 (October ed.).
[12] Pratt B, Loizos P. Choosing research methods: data collection for development workers. Dev Guidel 1992;7:126.
[13] Islam MS, Hossain HMZ, Hossain I. Environmental concerns in Khulna city, Bangladesh: it's causes, impacts and management. Bull Geol Sci 2006;11:25–39.
[14] Islam MS, Hossain HMZ, Hossain I. Solid waste problem in Khulna city, Bangladesh: it's environmental impacts and sustainable management. J Sci Culture 2008;74:251–8.
[15] Eddine BT, Salah MM. Solid waste as renewable source of energy: current and future possibility in Algeria. Int J Energy Environ Eng 2012;3:17.
[16] Amoo OM, Fagbenle RL. Renewable municipal solid waste pathways for energy generation and sustainable development in the Nigerian context. Int J Energy Environ Eng 2013;4:42.
[17] PREGA. Pormotion of renewable energy, energy efficiency and greenhouse gas Bangladesh 2005. Khulna city solid waste of electric generation. A pre-feasibility study report. Dhaka; 2005.
[18] Cheng H, Zhang Y, Meng A, Li Q. Municipal solid waste fueled power generation in China: a case study of waste-to-energy in Changchun city. Environ Sci Technol 2007;41:7509–15.
[19] Wazed MA, Islam MA. Prospect and future of biomass fuel: a review in Bangladesh perspective. Eng e-Trans 2010;5:61–6.
[20] Mondal MAH, Denich M. Assessment of renewable energy resources potential for electricity generation in Bangladesh. Renewable Sustainable Energy Rev 2010;14:2401–13.
[21] Mondal MAH, Denich M, Mezher T. Deployment of renewable energy technologies in Bangladesh: long-term policy implications in power sector. Energy Strategy Rev 2014;2:307–12.

[22] BPDB (Bangladesh Power Development Board). Annual report of 2006–2007. Dhaka, Bangladesh; 2008. Available: ⟨www.bpdb.gov.bd/download/Annual%20Report-10.pdf⟩.
[23] Parkin GF, Owen WF. Fundamentals of anaerobic digestion of wastewater sludges. J Environ Eng 1986;112(5):867–920.
[24] IEA: IEA energy technology essentials. IEA, Paris; 2007.
[25] Reddy PJ. Municipal solid waste management: processing – energy recovery – global examples. India: BS Publications; 2011; 449.
[26] Halder PK, Paul N, Hoque ME, Hoque ASM, Parvez MS, Rahman MH, et al. Municipal solid waste and its management in Rajshahi City, Bangladesh: a source of energy. Int J Renewable Energy Res 2014;4:168–75.